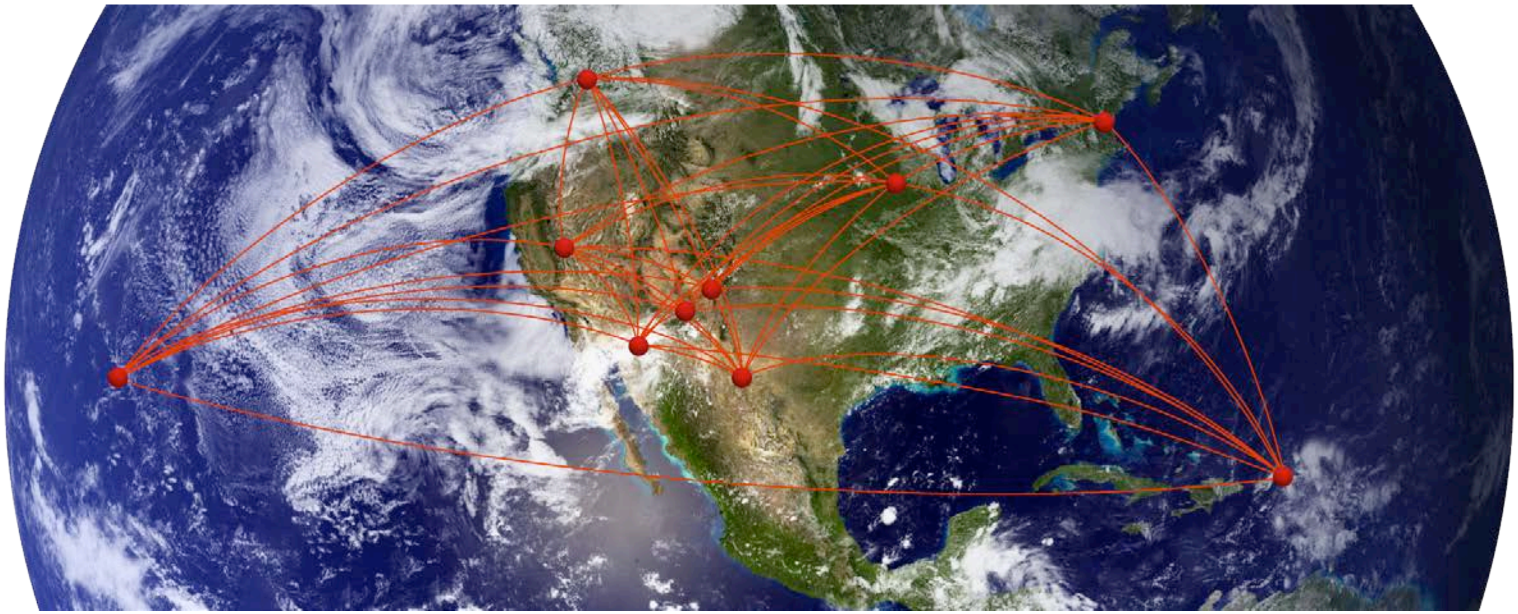
Cosmology, Black Holes, and AGNs with Water Megamasers

Jim Braatz (NRAO)



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Primary Goals of Megamaser Studies

1. Measure H_0 using *geometric* distances
   – Constrain models of cosmology and Dark Energy

2. Measure “gold standard” M_{BH} in external galaxies
   – M_{BH} scaling relations, galaxy evolution

1. Measure the geometry of the accretion disk and gas on sub-pc scales in AGNs

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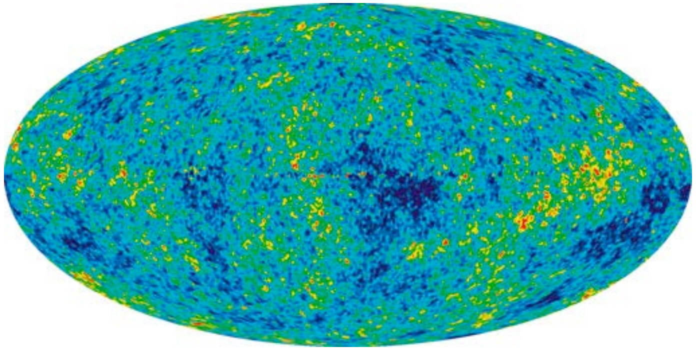
WMAP and Planck Maps of the CMB



Planck Results

Ade et al. 2013 (Paper XVI)

- In standard LCDM cosmology in a geometrically flat universe, Planck *predicts*
  H_0 = 67.3 +/- 1.2 km s^{-1} Mpc^{-1}

- Cepheid Measurements:
  H_0 = 73.8 +/- 2.5 km s^{-1} Mpc^{-1} (Riess et al. 2011)
  74.3 +/- 2.6 km s^{-1} Mpc^{-1} (Freedman et al. 2012)

- Chances that this is a statistical effect? 1:53

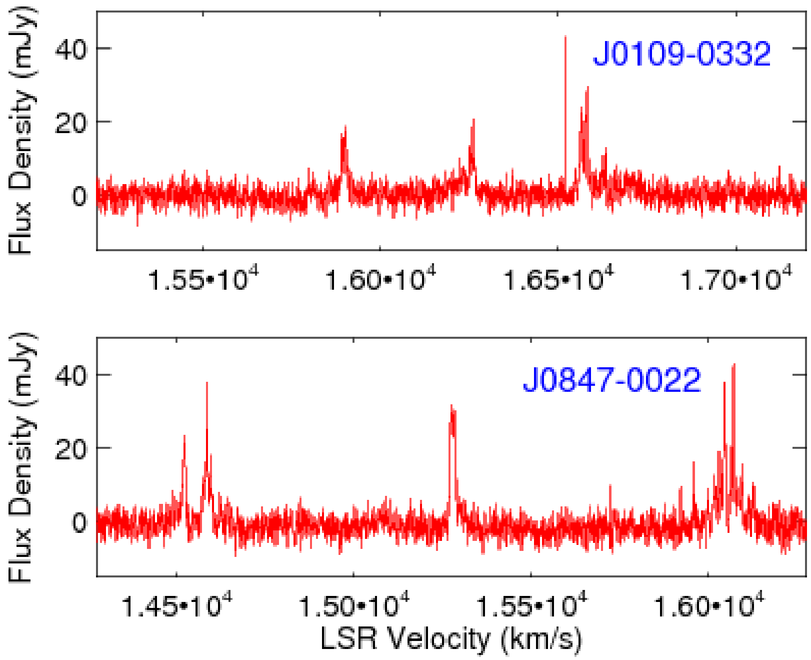
- New Physics?
- Unrecognized error in Measurements?

Steps to Measuring H_0 with the MCP

The MCP is an NRAO "Key Project" to measure H_0 precisely by measuring *geometric distances* to galaxies in the Hubble flow. It is a *one step* measurement, independent of all other methods.

1. Survey with the GBT to identify maser disk galaxies
2. Image the sub-pc disks with the High Sensitivity Array (VLBA+GBT+VLA+EB)
3. Measure accelerations in the disk with GBT monitoring
4. Model the maser disk dynamics and determine distance to the host galaxy

Survey Progress and Recent Disk Maser Discoveries



- 162 galaxies detected; over 3000 observed
- ~140 are in AGNs
- ~ 37 in disks
- ~ 8 appropriate for distances

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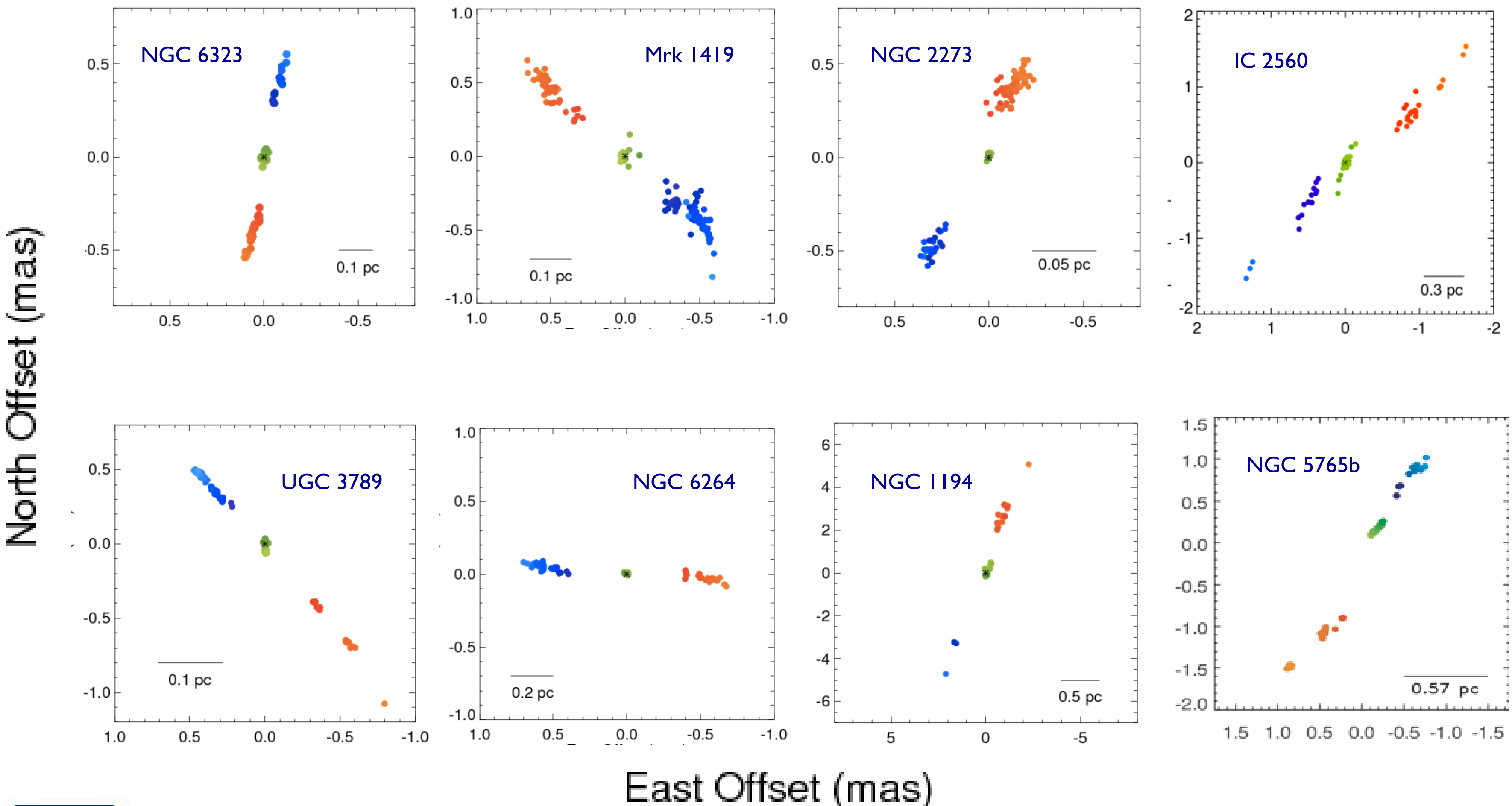
H_2O Megamaser Disks

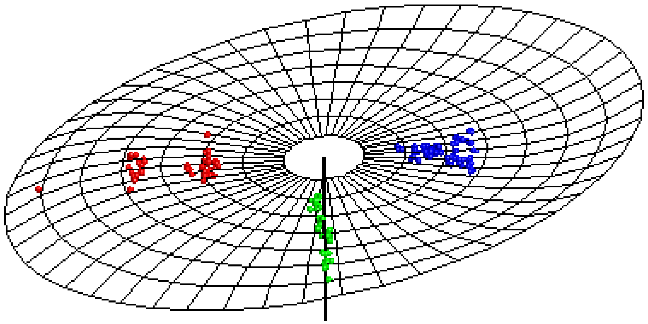


Measuring Distances to H_2O Megamasers: Bayesian Estimation of the H_0 PDF

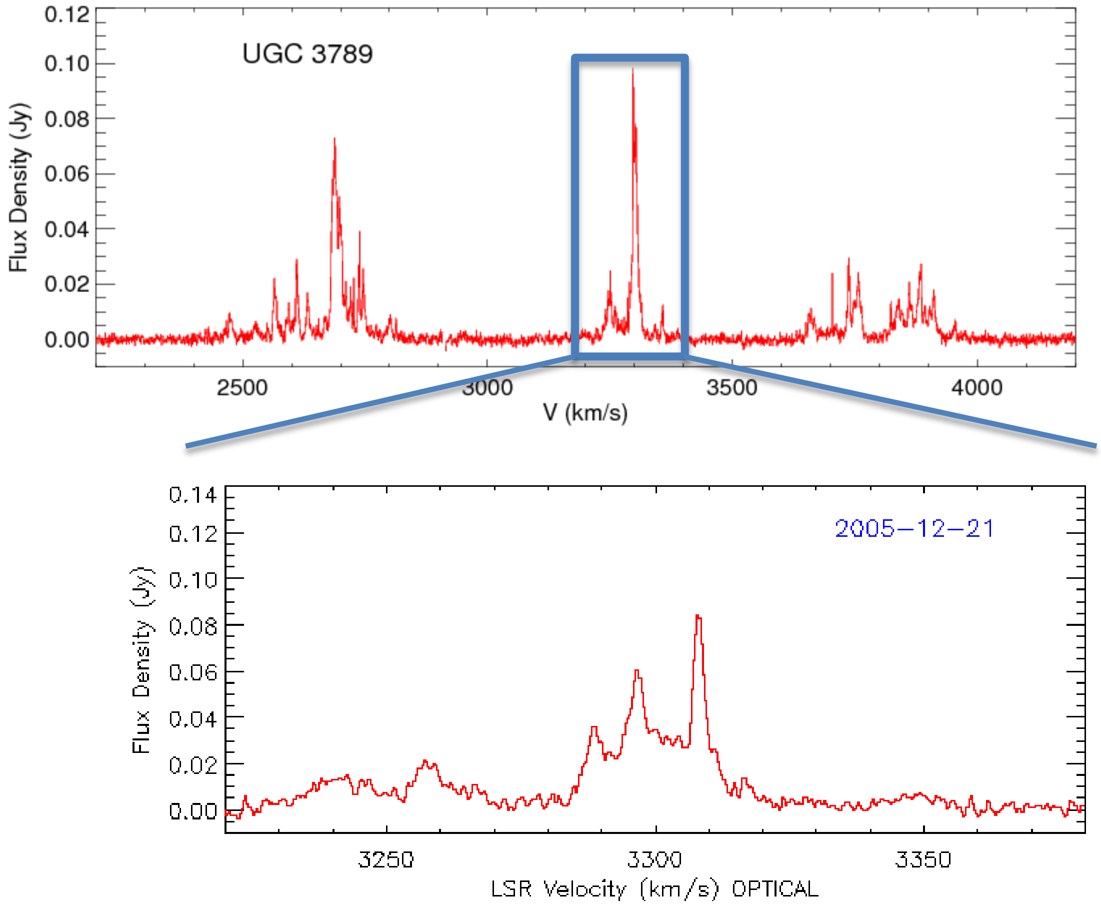
- We fit a warped disk model to the data and use a Markov chain Monte Carlo approach to measure parameters, including H_0. (Feng Gao will elaborate.)

- Two types of input data
  - VLBI map
  - Accelerations from GBT spectral monitoring

- Provide (x, y, v, a) for each maser spot



UGC 3789: Systemic Features



Estimation of H_0 from Geometric Distances

$H_0 = 68.6 \pm 5.5$ km s^{-1} Mpc^{-1} (8%)

UGC 3789	49.6 ± 5.1 Mpc	$H_0 = 69 \pm 7$	(Reid et al. 2013)
NGC 6264	137 ± 19 Mpc	$H_0 = 68 \pm 9$	(Kuo et al. 2013)

Including early results in progress:

$H_0 = 68.8 \pm 3.8$ km s^{-1} Mpc^{-1} (5.6%)

NGC 5765b	$H_0 = 65.5 \pm 7.0$	(Gao et al. in prep)
Mrk 1419	$H_0 = 74 \pm 14$	(Impellizzeri et al.; in prep)
NGC 6323	$H_0 = 90 \pm 20$	(Kuo et al; in prep)
IC 2560	$H_0 = 68 \pm 12$	(Wagner et al; in prep)

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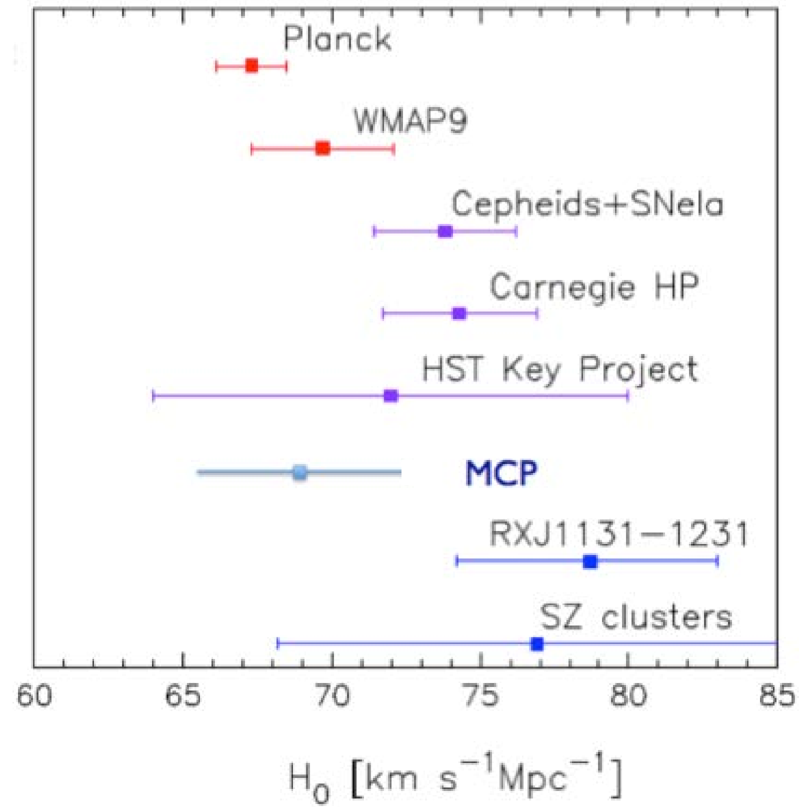
Improving the MCP Measurement of H_0

MCP will improve the measurement of H_0 by:

- Measuring additional galaxies
  - ESO558-G009
  - J0437+2456
- Improving our acceleration measurement techniques; modeling techniques
- Incorporating "blind analysis" methods
- SKA?



Update to Fig. 16
Ade et al. 2013 (Planck paper XVI)

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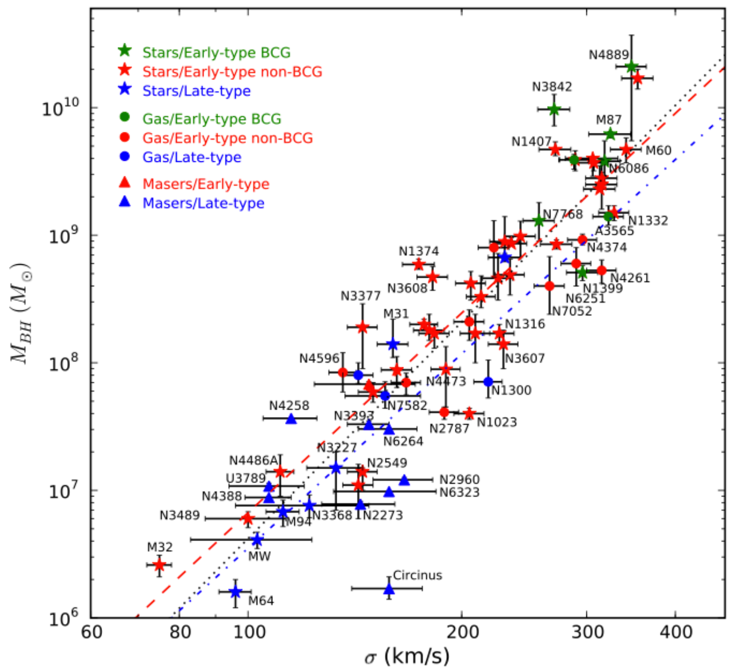
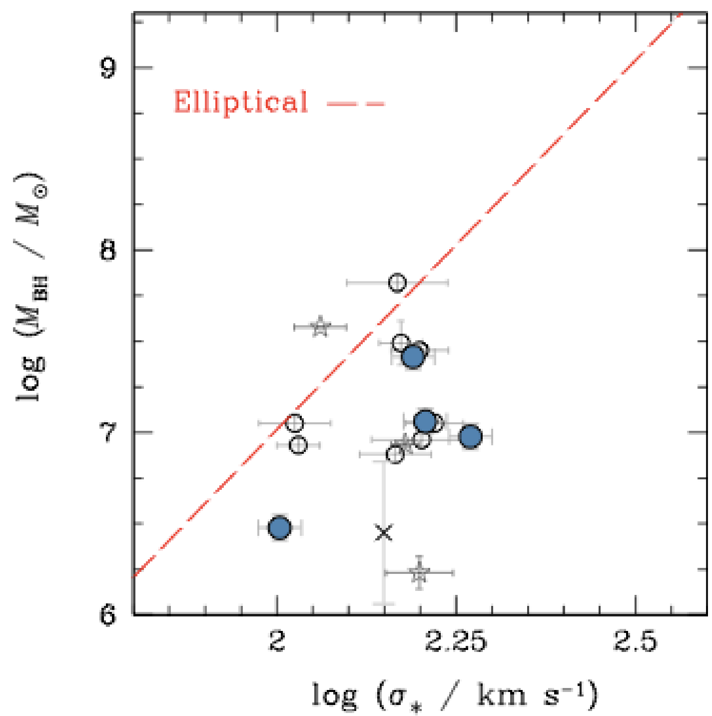
Measuring SMBHs to Learn How Galaxies Evolve

M-σ Relation



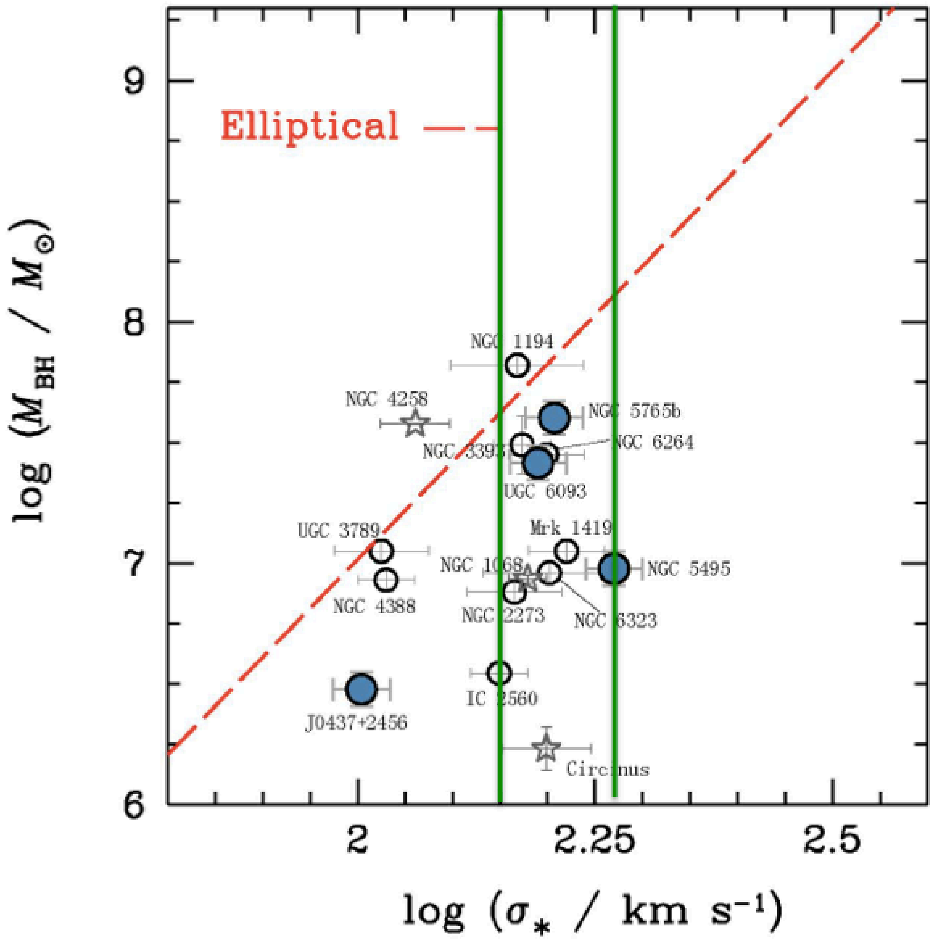
McConnell & Ma (2013)

M-σ Relation (Maser masses only)



Updated from Greene et al. 2010

M-σ Relation (Mega-maser BH mass only)



Intrinsic scatter:

Within σ = 140 – 185 km/s
M_{BH} = (2 – 56) x 10^6 M_{sun}

Galaxy types: S0 - Sc

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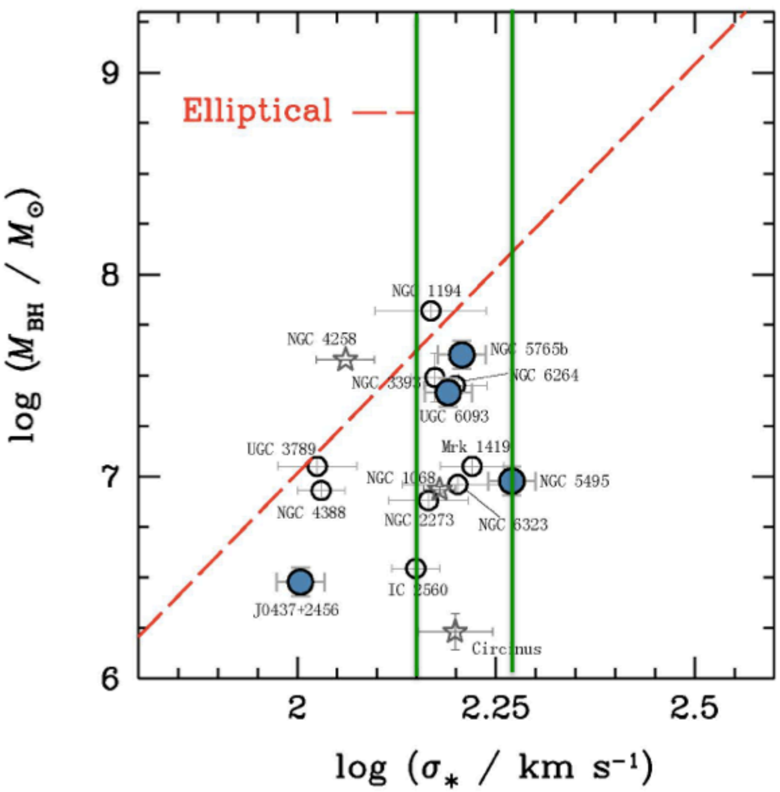
Low-mass BHs Important for Understanding BH Seeds



- "Light seeds" model
  - from pop III stars
  - Predict wide range of present-day BH masses, inc. very low mass systems
  - High occupation fraction
- "Heavy seeds" model
  - from collapse of massive gas clouds in halos
  - Minimum BH mass is higher
  - No very low mass BHs
  - Low "occupation fraction"
- Need more low-mass BH measurements

e.g. Volunteri & Natarajan 2009

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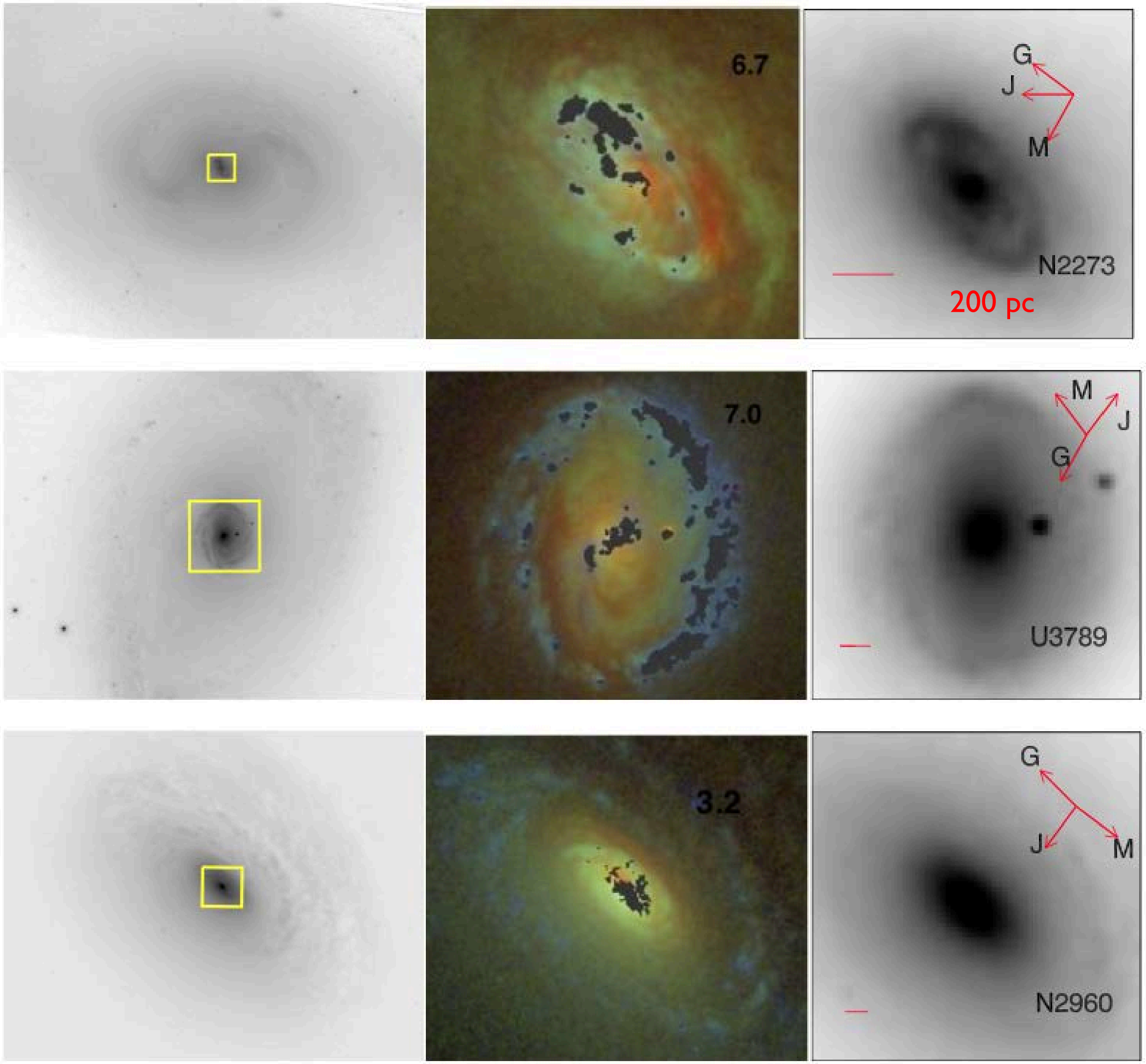
Probing BH Accretion in AGN



Maser disks align with jets, but misalign with all other galactic structures on scales >> 1 pc

Greene et al., 2013

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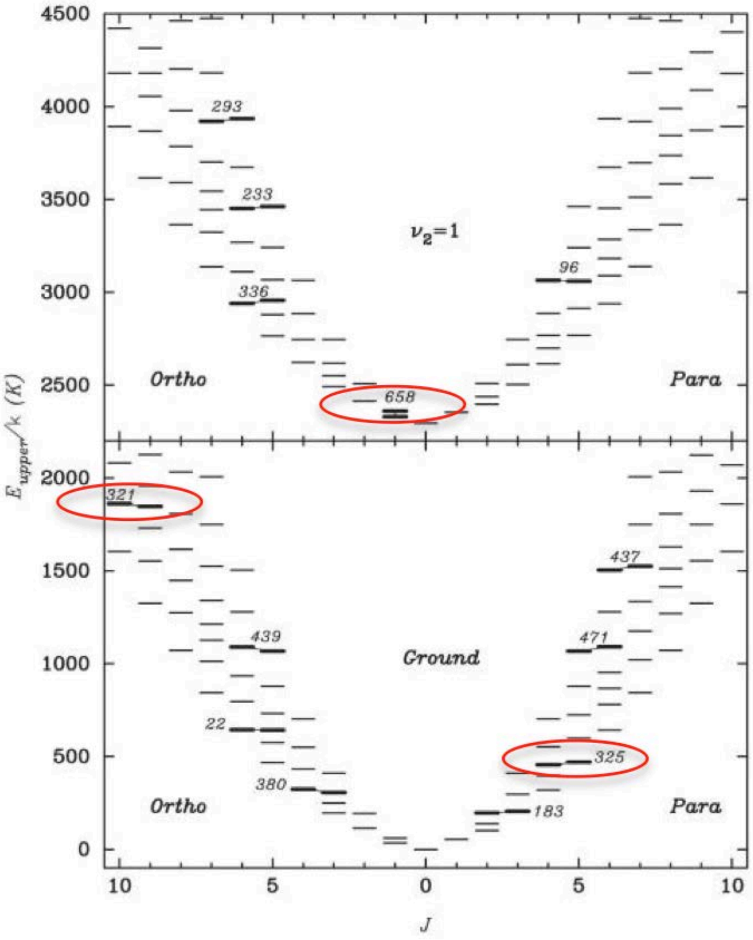
What about submm masers?



- H_2O molecule has multiple masing transitions in the sub-mm
- We are beginning an exploratory program to look for sub-mm masers in disks with ALMA in C2

Opportunities for China-USA Collaboration

- Expanding single-dish megamaser work
  - Increasing cadence of monitoring
  - Enabling more precise measurements of accelerations to improve distance determinations
  - Surveys at low and high redshift (K-band; Ku-band; X-band; C-band)

- Where appropriate, coordinate and expand VLBI and S-VLBI opportunities
  - Long baseline VLBI observations could reveal disk substructure and resolve blending

- We already have a successful exchange program with a student and postdoc, and ongoing collaborations

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Summary

- Megamasers are making fundamental contributions in AGN astrophysics and SMBH studies
- MCP measurement of H_0 is a critical test for fundamental physics
- We are approaching a 5% measurement: $H_0 = 68.7 \pm 3.7$ km s^{-1} Mpc^{-1} and work is ongoing
- Excellent opportunities for science collaboration and studies with the new generation of Chinese telescopes

The End